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L1: Entry 5 of 6 File: USPT Jun 13, 1989

DOCUMENT-IDENTIFIER: US 4839037 A
TITLE: Tapered, spirally wound filter cartridge and method of making same

Brief Summary Text (2):
The present invention relates generally to a spirally wound membrane filter element or cartridge for use in a standard cartridge filter housing together with a method for making such a cartridge, and more particularly, to a spirally wound cartridge, and method for making the same, in which the cartridge is tapered to provide a full fit with respect to the filter housing and to maintain relatively constant feed velocity over the membrane surface despite the passage of a portion of the feed through the membrane into the permeate tube.

Brief Summary Text (3):
Standard cartridge filter housings presently exist for receiving a filter cartridge. These standard cartridge filter housings are molded with a substantial draft angle or taper inside the sump portion of the housing to facilitate release of that part from the mold and, in some cases, to add strength to the sump. Such a filter housing comprises an elongated tapered sump portion having a closed bottom. If the housing is intended for use with a crossflow membrane filter element, it is also provided with a concentrate valve or orifice connected to the bottom. The housing also includes a housing cap through which the feed water or solution is introduced into the housing for exposure to the filter element and a permeate outlet for removing permeate or filtrate from the system.

Brief Summary Text (4):
Current technology with respect to the filter cartridges utilized in these cartridge housings ranges from standard pleated filter cartridges which utilize conventional "dead end" filtration technology and standard spirally wound membrane elements which utilize "cross flow" filtration technology. In "dead end" filtration technology there is no flow of feed water or solution relative to the membrane other than what passes through the filter media, while in "cross flow" filtration technology, the feed water, in addition to having a portion pass through the filter media, continually flows across the membrane surface and exits through a concentrate outlet port or valve. For purposes of this application, the term membrane is used to describe the filter material or media, whether it is technically a membrane or not. Conventional spirally wound membrane elements are generally cylindrical in shape and are formed by winding a relatively rectangular sheet of membrane material (together with appropriate spacer and permeate collection materials also relatively rectangular in shape) in a spiral configuration around a centrally disposed permeate tube or mandrel. This generally cylindrical filter cartridge is then disposed within the sump portion of the filter housing. However, because of the tapered configuration of the sump, the top portion of the filter cartridge is spaced inwardly from the interior surface of the upper end of the sump. A brine seal or concentrate seal is then positioned near the top of the filter cartridge between the outer surface of the cartridge and the inner wall of the sump. Such a seal is needed to force the feed solution, which is introduced at the top of the sump, to pass through the cartridge element flow channels defined by the spacer and over the membrane, and not around the outside between the sump wall and the outer surface of the filter cartridge.

Brief Summary Text (5):
While this construction is satisfactory in some applications, the provision of the brine or concentrate seal creates dead flow areas between the sump wall and the outer surface of the filter cartridge which can be havens for bacteria and other contaminants. Further, the above described structure requires the provision of such a brine or concentrate seal to operate sucessfully in the cross flow mode. This adds to the cost of the overall system, adds to the maintenance of it since such seal must be periodically cleaned, and limits its potential use since one more material with potential chemical incompatibility with the fluid is added to the filtration element. Further, existing spiral wound membrane cartridges lack uniform flow velocity over the entire membrane surface because of the fact that a portion of the feed water, during its passage through the membrane cartridge, is removed through the permeate outlet. Thus, during the passage of feed water or solution from one end of the cartridge to the other, the flow rate over the membrane surface decreases. This results in less predictable filter cartridge performance and shorter life of the membrane element due to the greater likelihood of cartridge plugging or blinding.

Brief Summary Text (8):
In contrast to the prior art, the present invention provides an improved filter cartridge for use in a tapered filter housing which utilizes cross flow filtration technology and which also eliminates the need for a brine or concentration seal required in prior art applications. The elimination of the brine or concentrate seal substantially reduces or eliminates possible areas for bacterial growth and other contaminants as indicated above and also reduces the cost of the system and improves and simplifies the maintenance thereof. The filter cartridge of the present invention also totally eliminates the dead areas between the outer surface of the filter cartridge and the inner surface of the sump and thereby increases the possible filter area by more efficiently utilizing the available space in the sump. The improved filter cartridge of the present invention also provides for relatively uniform feed water flow across the membrane surface despite the fact that a portion of the feed water passes through the membrane and exits through the permeate outlet.

Brief Summary Text (9):
More specifically, the present invention provides a spirally wound, tapered filter cartridge which is larger at one end than the other and a method for making the same. In the preferred embodiment and method, the filter cartridge of the present invention is designed so that its outer side wall is tapered at an angle which approximates the taper of the sump portion of the filter housing. Thus, when the filter cartridge is inserted into the housing sump, a full fit relationship is provided between the outer surface of the filter cartridge and the inner surface of the sump. As indicated above, this eliminates the need for the brine or concentrate seal, thereby reducing the cost of the system. Such a design also simplifies the maintenance of the system and substantially reduces the potential dead flow areas and sites for bacteria and other contaminants to collect and grow. Further, the amount of membrane area in such filter cartridge is increased over that of conventional cartridges because of the fact that the filter cartridge of the present invention is designed to completely fill the tapered sump.

Brief Summary Text (11):
Another object of the present invention is to provide an improved, spirally wound filter cartridge which eliminates the need for a brine or concentrate seal when used with a tapered sump and which also provides more uniformity of feed water flow over the entire membrane element.

Drawing Description Text (8):
FIG. 7 is a cross-sectional view of a portion of a filtration materials sandwich showing the membrane, the permeate carrier and the spacer mesh.

Drawing Description Text (9):
FIG. 8 is a graph plotting feed flow (in gallons per minute) against fluid velocity through the cartridge (in feet per second) for both a conventional cylindrical, spirally wound filter cartridge of the prior art and the tapered, spirally wound filter cartridge of the present invention.

Detailed Description Text (8):
The bottom surface of the base 48 is provided with a plurality of recessed portions or channels 49. These channels 49 allow for the concentrate to flow from the bottom end of the sump 10 into and through the outlet opening 15. In the present embodiment, the concentrate comprises that portion of the feed which has passed through the cartridge and across the membrane and exits through the end opposite the end cap.

Detailed Description Text (11):
The construction of the cartridge filter 35 is similar to conventional spirally wound cartridge filters in that it includes a center permeate tube or mandrel 36 and a plurality of layers 51 of a filtration materials sandwich, but is different in that the assembled cartridge 35 is tapered in the aforementioned manner. In the preferred embodiment, as illustrated best in FIG. 7, each of the spirally wound layers 51 of the cartridge 35 includes a pair of membrane elements 58, a permeate collection material 59 disposed therebetween, and a mesh spacer 60, all of which are well known and conventional in the art. In the preferred embodiment, the angle between the edges of 54 and 56 is between about 60.degree. and 75.degree. to produce the preferred taper in the resulting cartridge.

Detailed Description Text (12):
The method of assembling or manufacturing the tapered cartridge 35 of the present invention is illustrated best in FIG. 6. As shown, the permeate tube or mandrel 36 is connected with an edge of a sheet of a filtration materials 51 comprising similarly configured sheets of membrane 58, mesh spacer 60 and permeate collection material 59 as shown in FIG. 7. The sheet of filtration materials 51 is defined by a tube connection edge which is secured to a portion of the elongated permeate tube or mandrel 36 in a direction generally parallel to its axis, a pair of side edges 54 and 55 and a biased or beveled edge 56. It should be noted that the side edge 55 is shorter than the end edge 54. This results in the outer edge 56 being angled or tapered as shown in FIG. 6. It should also be noted that the permeate tube 36 includes a plurality of openings 52 (FIG. 4) which, when the filter material 51 is secured to the tube 36, are positioned between the pair of membrane sheets 58 in a manner known in the art.

Detailed Description Text (14):
The edges 54, 55 and 56 of corresponding pairs of membrane sheets 58 are then glued or otherwise secured to one another, with the permeate collection material 59 disposed therebetween in the manner illustrated in FIG. 7. When this is done, the sheet of filtration materials 51 is spirally wound around the tube or mandrel 36. When this is completed, it is temporarily taped until the glue applied to the edges has cured, at which time the tape is removed. The resulting cartridge is a spirally wound cartridge having a tapered configuration as shown in FIGS. 1 and 4. Such a cartridge, when inserted into the sump 10, fits into the configuration of the interior wall 13 to substantially eliminate any dead space areas between the outer surface of the cartridge 35 and the wall 13.

Detailed Description Text (18):
It should also be noted, as described above in connection with the summary of the invention, that the tapered cartridge 35 of the present invention provides for more uniformity of flow over the membrane surface during operation. In a crossflow mode, feed water or solution is introduced at the top end of the cartridge 35 as shown in FIG. 1 and is caused to flow through the spacer element 60 (FIG. 7) toward the lower end of the cartridge 35. During this flow, the feed is exposed to the surface

of the membranes 58 under pressure and a portion is caused to pass through the membranes 58 and into the area therebetween defined by the permeate collection material 59 as a result of pressure in the system. Thus, during flow of the feed from the top to the bottom of the cartridge 35, a certain portion of the feed will pass through the membrane material 58, into the center of the permeate tube 36 through the openings 52 and out through the permeate outlet 21. In a typical filtration system the amount of feed which passes through the membrane, normally referred to as the recovery, is between about 8% and 20% and preferably about 15%. However, in some applications, the recovery can be as high as 50%-75% or more. For purposes of the present application, the recovery equals a fraction whose numerator is the feed rate minus the permeate rate and whose denominator is the feed rate and which fraction is multiplied by 100%.

Detailed Description Text (19):
When a conventional, cylindrically shaped filter cartridge is used in a filter housing of the type illustrated in FIG. 1, the membrane area and feed channel volume to which the feed is exposed is constant from the top of the cartridge to the bottom. Thus, because a portion of the feed passes through the membrane and out through the permeate tube 36 during operation, the velocity of the feed decreases as it flows through the cartridge. With the tapered cartridge of the present invention, however, the surface area of membrane exposed to the feed decreases from the top to the bottom of the cartridge 35. This will tend to maintain the velocity of the feed at a more uniform level from one end of the cartridge to the other despite the loss of some of the feed through the permeate tube 36.

Detailed Description Text (20):
FIG. 8 is a graph plotting velocity of feed versus feed flow in gallons per minute assuming a permeate flow of one gallon per minute. As shown, for a conventional, cylindrical cartridge, difference in velocity is maintained between the upstream end (illustrated by reference numeral 61) and the downstream end (illustrated by numeral 62) regardless of the feed flow through the system. On the other hand, the graph in FIG. 8 shows that for certain feed flows, the difference between the upstream velocity and the downstream velocity for a tapered cartridge of the present invention is nearly the same. In fact, as illustrated on the graph of FIG. 8, a feed flow of between 7 and 7.5 gallons per minute, with a permeate flow of one gallon per minute, will result in substantially uniform velocity of the feed over the entire length of the cartridge. This is a significant advantage of the present cartridge design since the cleaning action of the feed velocity on the membrane surface is important to attaining economcial filter life, so the tapered cartridge design optimizes the life of the cartridge, provides for a more predictable cartridge performance and results in a higher membrane flux.

CLAIMS:

1. A spirally wound, cross flow filter cartridge comprising:

an elongated, centrally disposed permeate tube having a first set of openings;

a sheet of filtration materials spirally wound around said permeate tube, said sheet of filtration materials comprising a pair of membrane elements and a permeate carrier disposed therebetween, said pair of membrane elements having corresponding edge portions sealed to said permeate tube with said first set of openings disposed therebetween and the remaining edge portions sealed to one another;

said cartridge having first and second transverse ends generally circular in configuration and an outer surface portion joining said ends in which said first end is greater in diameter than said second end and said outer surface is tapered from said first end to said second end, said first end defining an inlet end which is uncapped and capable of receiving fluid flow and said second end defining an outlet end which is uncapped and capable of providing fluid flow whereby fluid to

be filtered enters said inlet end and flows longitudinally in a direction generally parallel to said permeate tube toward said outlet end with at least a portion of said fluid passing through one of said membrane elements and into said permeate tube through said first set of openings.

4. The filter cartridge of claim 1 wherein said sheet of filtration materials includes a spacer sheet disposed between adjacent membrane elements, said spacer sheet being in communication with said inlet and outlet ends and defining a flow path for fluid between said inlet and outlet ends.

5. A cross-flow filtration device comprising:

a filter cartridge housing having an elongated sump having an open top, a closed bottom and a tapered side wall extending between said top and bottom, said top being larger than said bottom and said tapered side wall having a greater diametrical dimension at its top than at its bottom;

an end cap connectable with said open top; a spirally wound, tapered filter cartridge disposed within said sump and comprising:

an elongated, centrally disposed permeate tube having a first set of openings;

a sheet of filtration materials spirally wound around said permeate tube, said sheet of filtration materials comprising a pair of membrane elements and a permeate carrier disposed therebetween, said pair of membrane elements having corresponding edge portions sealed to said permeate tube with said first set of openings disposed therebetween and the remaining edge portions sealed to one another;

said cartridge having first and second transverse ends generally circular in configuration and an outer surface portion joining said ends in which said first end is greater in diameter than said second end and said outer surface is tapered from said first end to said second end, said first end defining an inlet end which is uncapped and capable of receiving fluid flow and said second end defining an outlet end which is uncapped and capable of providing fluid flow whereby fluid to be filtered enters said inlet end and flows longitudinally in a direction generally parallel to said permeate tube toward said outlet end with at least a portion of said fluid passing through one of said membrane elements and into said permeate tube through said first set of openings;

a permeate outlet in said end cap;

means for connecting said permeate outlet with said permeate tube;

a feed inlet in said end cap; and

means for connecting said feed inlet with said first end of said filter cartridge.

13. The filtration device of claim 5 wherein said sheet of filtration materials includes a spacer sheet disposed between adjacent membrane elements, said spacer sheet being in communication with said inlet and outlet ends and defining a flow path for fluid between said inlet and outlet ends.

14. A method of making a cross flow, tapered filter cartridge having a pair of transverse, generally circular first and second ends which are uncapped and capable of receiving and providing fluid flow, respectively comprising the steps of:

laying up a sheet of filtration material having a permeate tube connecting edge, first and second side edges each having a first end adjacent to a respective end of said permeate tube connecting edge and extending therefrom at substantially right angles and a beveled edge generally opposite to said permeate tube connecting edge

and adjacent to a second end of each of said side edges, said first side edge being longer than said second edge, said sheet of filtration material comprising a pair of similarly configured membrane material sheets and a permeate carrier sheet disposed therebetween;

securing said permeate tube connecting edge to a permeate tube having a first set of openings with the permeate tube connecting edges of said pair of membrane sheets being secured to said tube on opposite sides of said first set of openings;

gluing said pair of membrane material sheets together, with said permeate carrier sheet disposed therebetween, along said side edges and said beveled edge; and

spirally winding said filtration material around said permeate tube.

16. The method of claim 14 wherein the step of laying up a sheet of filtration material includes laying up a sheet of filtration material comprising a similarly configured spacer sheet disposed between adjacent membrane material sheets.

17. A method of making a cross flow, tapered filter cartridge having a pair of transverse, generally circular first and second ends which are uncapped and capable of receiving and providing fluid flow, respectively comprising the steps of:

laying up a sheet of filtration material having a permeate tube connecting edge, first and second side edges each having a first end adjacent to a respective end of said permeate tube connecting edge and extending therefrom at substantially right angles and an edge generally opposite to said permeate tube connecting edge and adjacent to a second end of each of said side edges, said sheet of filtration material comprising a pair of similarly configured membrane material sheets and a permeate carrier sheet disposed therebetween;

securing said permeate tube connecting edge to a permeate tube;

gluing said pair of membrane material sheets together with said permeate carrier sheet disposed therebetween, along said side edges;

partially spirally winding said filtration material around said permeate tube;

cutting said sheet of filtration material at a bevel relative to the longitudinal axis of said tube;

gluing said pair of membrane material sheets together along said beveled edge; and

completing the spiral winding of said filtration material around said permeate tube.

19. The method of claim 17 wherein the step of laying up a sheet of filtration material includes laying up a sheet of filtration material comprising a similarly configured spacer sheet disposed between adjacent membrane material sheets.

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L1: Entry 6 of 6 File: USPT Mar 21, 1989

DOCUMENT-IDENTIFIER: US 4814079 A
TITLE: Spirally wrapped reverse osmosis membrane cell

Abstract Text (1):
A spirally-wrapped reverse osmosis membrane cell employing an envelope of semipermeable membrane sheets spirally wound or wrapped about a tubular mandrel. The convolutions of the membrane assembly are separated to form an open channel, directed feed flow path leading into a lateral opening or series of openings in a communicating tubular member defining an unobstructed bore throughout its length. The feed separator may comprise a plurality of substantially parallel strips of impermeable material of a thickness sufficient to provide desired separation between membrane sheets and wherein the strips define a meandering fluid flow path throughout the length and width of the membrane sheet.

Brief Summary Text (3):
This invention relates generally to the art of reverse osmosis and ultrafiltration, and in particular, to reverse osmosis, ultrafiltration, or microfiltration devices employing an envelope of semipermeable membrane sheets spirally wound or wrapped about a tubular mandrel. The convolutions of the wound membrane sheet or sheets are separated from one another and a feed solution is introduced therethrough with permeated fluid passing through the membranes by a pressure driving force and discharged into the hollow mandrel.

Brief Summary Text (5):
In reverse osmosis, ultrafiltration and microfiltration devices, an impure solution or a solution to be concentrated is brought into contact with a semipermeable membrane. A pressure is applied to the solution to force liquid (the permeate) through the membrane, thereby filtering or concentrating the initial solution. Membranes can be selected for a particular use by comparing the average porosity of the membrane and the size or molecular weight of the solute or particles of the starting solution. Moreover, membranes may be of two different shapes, e.g. hollow tubes or flat sheets. The flat sheet membrane can be installed in devices in spirally-wound, or with plates and frames configurations. In the spiral-wound system, one or more flat sheets of membrane material are wound around a perforated permeate collection tube. Fluid flow through the modules is unidirectional, i.e. permeate passes through the membrane to the collection tube, while the concentrated residue passes along one side of the membrane to be collected or discarded. The membrane sheets are sealed on three of the four edges and the fourth edge is sealed to the collection tube and communicates therethrough through the perforations.

Brief Summary Text (6):
Examples of prior art spiral-wound modules are described in U.S. Pat. Nos. 3,695,446; 3,827,564; 3,813,334; 3,928,204; 3,367,504; 3,173,867 and 2,599,604. Examples of patents providing a meandering course for the flow of feed fluids are shown in the Newman Patent No. 4,053,418 and the French Publication No. 2,211,274 published July 19, 1974.

Brief Summary Text (7):

The prior art devices, as exemplified by the above-referenced patents, in general, utilized grid-like or mesh layers for maintaining the gap adjacent the semipermeable membranes. The mesh or open grid separator defines the feed water channel dimensions. Unfortunately, the flow of fluid across the surface of the membrane was controlled by and often hindered by such separators.

Brief Summary Text (8):
The surface of the membrane must be washed with the flow of the feed fluid across the surface of the membrane to prevent concentration polarization of ionic salts and suspended solids. In the case of reverse osmosis membranes and salt solutions a velocity of 0.5 to 1 foot per second is sufficient to minimize concentration polarization when the feed water does not contain suspended solids. When suspended solids are present, they tend to concentrate at the membrane surface as the water passes through the membrane. Even in very low concentrations the solids can form a film on the surface which reduces the production rate of the membrane. Increasing the transverse velocity of water across the surface of the membrane reduces the thickness of the film of suspended solids and maximizes the production rate. Conventional limits of suspended solids at the low velocities is a Silt Density Index of less than 5 and a maximum turbidity of one Nephelometric Turbitiy Unit (NTU), when using conventional commercial spiral wound reverse osmosis elements. This usually represents a suspended solids concentration of less than 1 part per million (ppm).

Brief Summary Text (9):
In many cases, particularly where there are relatively few suspended solids, the usual grid or mesh separator sheets that are found in commercial reverse osmosis elements will suffice to provide sufficient flow of fluids. However, it has been found in certain installations, and in particular where it is desired to pretreat water taken from flowing rivers and the like, the source is often quite turbid. Conventional devices tend to foul quickly with the mesh or grids of the separators becoming clogged, and the membrane becoming fouled, thereby reducing the operating hours between cleanings, increasing the operating pressure to maintain a given production rate, or reducing the production rate. To achieve higher velocities a open feed channel separator is required. This has normally been accomplished with plate and frame hollow tube or hollow fiber devices. However, spiral wound devices are less expensive to construct since they normally use a tube as a container.

Brief Summary Text (10):
The Newman Patent No. 4,053,418 discloses a coiled dialyzer used in artificial kidney systems wherein there is an embossed support member constructed to prevent the membrane from contacting the web of the same support member to assure uniform dialysis flow between the membrane and the web. In this case the separator is in the form of an imperforate, impermeable web and includes integrally formed embossed ribs which define angular flow channels, and also act to separate the support or web from the semipermeable membrane. The Heden U.S. Pat. No. 3,352,422 provides "saw tooth" obstruction in "plate and frame" type of dialysis apparatus. Thus a cylindrical disk includes a center hole for passing through one of the flows of fluid and spirally formed grooves, the inner end of the same being placed in the proximity of the center hole. The saw-tooth formation is applied to the edges or ridges of the grooves.

Brief Summary Text (11):
A spirally wound membrane construction was also disclosed in the French Publication No. 2,211,274, wherein the membrane construction included a tubular member comprising two tubular sections separated from one another by means of a cylindrical watertight plug inserted into one end of each section. Each section includes a lateral or side opening communicating with a recessed passage in the membrane composite. The continuous recessed passage is generally U-shaped, with a separate tongue-like portion extending laterally from the area of the plug when one end of the membrane composite has been secured to the tubular mandrel. Thus, the

fluid to be separated or filtered enters one section of the mandrel, leaves that section via its lateral opening and into one side of the U-shaped passage and around the projecting "tongue" to exit on the other side and into the lateral opening of the opposite tubular section.

Brief Summary Text (12):
The aforementioned Newman and French patents are examples of open feed channels where guidance ribs or paths are used. Their methods of construction are relatively expensive to manufacture. There are other limitations to their respective designs. The Newman design is intended for dialysis applications where differential pressures are low and the membrane homogenous. In reverse osmosis applications, where the differential pressure or driving force across the membrane is on the order of 400 psi, the projections on the surface of the separator would stretch and rupture the membrane. The membrane would also lie tightly against the surface of the permeate separator, restricting the flow of the permeate. In the French design, only one active membrane surface is exposed to the flow of the feed solution. This severely limits the total amount of membrane area that can be placed in the spiral element. It would also limit the number of sheet assemblies or leaves that can be installed. An element that would contain a large surface area would also have an extremely long flow path which would create a relatively high pressure drop, and would limit the surface velocities of the feed water over the membrane surface.

Brief Summary Text (13):
Conventional commercial spiral wound reverse osmosis element designs and other spiral designs, such as disclosed in the Westmoreland Patent No. 3,367,504, use a grid or mesh in the feed flow path which obtructs or interferes with the free flow of feed water. The mesh or grid restricts the cross sectional area of the flow path. Turbulence is created between the strands. These effects combine to create high pressure drops in the feed channel at high velocities. The typical feed channel pressure drop in a 40 inch long reverse osmosis element is 10 psi at one foot/second and 220 psi at 4 feet/second. It is clear from this example that the surface velocities of the conventional spiral wound elements is limited to a maximum velocity of one foot per second. The pressure drop of the flow channel increases when the water contains suspended solids. This further limits the velocity of water in the feed channel. The water directly behind the strands of mesh is relatively stagnant. The suspended solids tend to deposit underneath the strands of the mesh. This fouls microfiltration, ultrafiltration, and reverse osmosis membranes with a thick layer of deposited solids buildup.

Brief Summary Text (15):
There is provided by virtue of this invention a relatively inexpensive separator means for spirally-wound membrane module assemblies, which eliminates the need for mesh or grid-like supporting materials disposed between the membrane sheets. The improvement may be made to conventional semipermeable membrane devices without change of construction of the casing retaining the coiled membrane sheet, the conventional membrane sheet, itself, the mandrel, or to backing material conventionally applied to the semipermeable membrane layer or layers.

Brief Summary Text (16):
The invention consists of an assembly comprising spiral-wound microfiltration, ultrafiltration and reverse osmosis elements formed with an open channel, directed feed flow path and into a lateral opening or series of openings in a communicating tubular member defining an unobstructed bore throughout its length. The flow of fluid across the surface of the membrane is controlled by the feed separator. The feed separator may comprise a plurality of substantially parallel separator strips of impermeable material of a thickness sufficient to provide desired separation distance between membrane sheets, and which strips may take the form of opposed marginal strips terminating at one end thereof at the aforementioned hollow, perforated mandrel and extending to communicate with entrance and exit openings, which may include a short length of a mesh or grid strips, and located at the

terminal end of the wound membrane sheet or sheets. Intermediate the marginal strips are alternatively arranged intermediate strips which may be of the same material as the marginal strips or are disposed on the same membrane surface as the marginal strips and substantially parallel therewith. That is, one end of intermediate strips is disposed proximate to the hollow mandrel, whereas its distal end terminates at a point spaced from the terminal edge of the wound membrane sheet. Alternate intermediate strips have their respective ends positioned approximate the distal edge of the membrane and extend inwardly with the inner ends thereof being spaced from the hollow mandrel. This arrangement provides a meandering or serpentine path for fluids entering the spirally-wound assembly through the entrance and exit openings located at opposite marginal sides thereof. Thus, there is a relatively unimpeded flow of fluid, which has a longer contact time in its path by the meandering arrangement, in contrast to flow of fluid through the grid or mesh-like supporting material to thereby be eventually restricted by collection of sediment carried by the fluid stream.

Brief Summary Text (17):
It is therefore a primary objection of this invention to overcome problems which may arise from application of the semipermeable membranes acting upon waters or other fluids containing high levels of suspended solids. The desired mechanical configuration provides limitation on the velocity of fluid passing over the membrane particularly in the conventional spiral-wound design which is relatively wide with a short feed channel typically 36 to 60 inches wide and 35 to 55 inches long.

Brief Summary Text (18):
It is another object of the present invention to provide a spiral-wound membrane module that takes advantage of an open feed channel to maintain a maximum flux rates of the membrane or membranes by maintaining a minimum transverse velocity of 3 to 10 feet per second. For instance, a typical conventional commercial 4 inch spiral wound reverse osmosis element has a maximum feed flow rate of 16 gpm. It contains about 70 square feet of membrane area and three or four leaves. Each leaf has two membranes with a total area of 17.5 to 23.3 square feet. The dimension of a leaf is typically 36 inches by 35 to 43 inches long including an overwrap area. The mesh that forms the feed separator is typically 0.030" thick. The cross sectional area of the flow path is 0.030".times.43" or 1.29 square inches. At a maximum flow rate of 5.3 gpm per leaf the velocity of the feed water is about 1.32 feet per second. To increase the velocity to 9 feet per second would require a feed flow rate of 36 gpm per leaf or 108 gpm per element. The feed port connection is typically a 3/8 inch pipe. The velocity within the pipe would be on the order of 200 feet per second. Clearly the pressure drop in the feed pipe, along with entrance and exits losses, and the pressure in the element would be extremely high and totally impractical. To obtain the high velocities within the element requires that it be done with the normal flow range of 8 to 16 gallons per minute (gpm). In the separator of the invention the flow path is divided by the flow path strips. The typical flow path width is about 9 inches wide. The cross sectional area of the flow path is 0.27 square inches. At the maximum shell flow rate of 16 gpm at 5.3 gpm per leaf, the velocity is 6.3 feet per second. Reducing the leaves from 3 to and maintaining the total area by increasing the length of the leaves produced a velocity of 9.5 feet/second at 16 gpm. The configuration disclosed herein minimizes the flow rate required to produce a reasonably high velocity with a minimum pressure drop.

Brief Summary Text (19):
Another object of the present invention is to provide spiral-wound membrane elements or devices which are relatively economical to manufacture since such wound devices utilize relatively inexpensive pipes or conduits as containment vessels. Prior plate and frame designs are generally more expensive to manufacture since the separators are injection molded or die cut from sheet stock and machined. End plates and stongbacks require welding and machining and the clamping system is

relatively expensive to manufacture.

Brief Summary Text (20):
It is still another object of the present invention to provide a modified spiral-wound module utilizing the same flow rate per element as used in conventional spiral-wound designs, but with a velocity of approximately seven times that of prior designs. The design balances the economy of manufacturing with high performance of directed flow open channels and allows the simple replacement of the elements in existing systems without flow rate changes.

Drawing Description Text (2):
FIG. 1 is an elevational view, partly in section and with parts broken away of one embodiment of a spiral-wound reverse osmosis membrane cell in accordance with the present invention;

Drawing Description Text (4):
FIG. 3 is a perspective view of a membrane layup as seen during the fabrication of a membrane module of the unit of FIG. 1;

Drawing Description Text (5):
FIGS. 4 and 5 are plan views of a variation in embodiments of the present invention and illustrate the present invention as applied to a semipermeable membrane unit prior to spiral winding or wrapping the membrane sheet around a perforated hollow mandrel member;

Detailed Description Text (2):
As stated above, the present invention consists of a device wherein spiral wound microfiltration, ultrafiltration and reverse osmosis elements are formed to provide an open channel, directed feed flow path. Flow of fluid across the surface of the membrane is controlled by the feed separator. The feed separator is a flat sheet with a flow path cut out to direct the feed flow. The channel that is created between the membranes is thin, narrow, open and directed in a serpentine or meandering path across the membrane surface. The entrance or exit of water into or out of the separator is provided by a flow strip. This is a strip of grooved material or a strip of mesh that allows water to enter or exit the separator while providing support to maintain the separation of the membranes. The flow strip can be thicker than the feed separator to minimize its pressure drop, as illustrated in FIG. 7 and described hereinbelow. The separator is wound along with the membranes in a spiral to form the element. The element is inserted into a pressure vessel or casing to confine and separate the processed fluids.

Detailed Description Text (3):
Thus, with particular reference to the views of FIGS. 1 and 2 of the drawings, there is provided a membrane module indicated generally at 10, a casing 11 for containing the module, a feed solution entrance assembly 12 and a rejected or concentrated solution assembly 13.

Detailed Description Text (6):
The central tube 24 is further supported at opposite ends in central openings of anti-telescoping devices or cylindrical spiders 30. As shown in cross section in FIG. 2, both the upper and lower spiders 30 are substantially identical and contain a plurality of openings 31; in this case four each. Each spider 30 may be made of a plastic material having an outer stepped diameter to provide a sealing engagement with the casing 11, the caps 16 and 18, and the membrane module 10. It will be observed that there is provided an upper chamber 34 and a lower chamber 35. The upper chamber collects the feed solution entering from the inlet pipe 15, which is further guided to the membrane module 10 through the apertures 31 of the upper spider 30, whereas the lower chamber 35 collects the concentrate entering from the apertures 31 of the lower spider 30 and permits it to exist through the outlet pipe 19. As will hereinafter be described, the permeate exits through the permeate tube

portion 26 of the central tube 24, having entered the tube through the apertures 25 from the membrane module 11. The plug 27 prevents entry of fluid into the central tube.

Detailed Description Text (7):
FIG. 3 discloses the features of the membrane module 10 and its method of fabrication with particularity. The module 10 includes the central mandrel or tube 24, upon which a membrane layup comprising an envelope 41 and an overwrap 42 is spirally wound. The envelope 41 comprises a semipermeable membrane and backing material layers 44 and an intermediate permeable support 45. The materials of the membrane and backing layers 44 and 45 are quite conventional, and it will be seen from FIG. 3 that the membrane and backing layers are suitably bonded together to provide a fluid-tight seal along three edges using a conventional adhesive 43 to thereby provide the envelope 41, but with the fourth edge left open to seal with the tube 24 (see FIG. 4).

Detailed Description Text (8):
The semipermeable membrane 44 is generally in the form of a thin sheet of material having predetermined permeation properties. A suitable material for the semipermeable membrane 44 is of a non-woven polypropylene fabric, with a linear polysulfone microfiltration or ultrafiltration layer cast thereon, and including a cast layer of a polyamide condensation polymer that is formed by an interface between two solutions which normally give reverse osmosis characteristics when required. Although only one bag leaf or envelope 41 is shown herein, there may be two or more bags attached to the tube if and when desired to increase the total surface area.

Detailed Description Text (9):
The present construction presents particular advantages where the conditions of the fluid to be separated are particularly dirty or full of silt or other turbidity which is not present in the usual prior art devices needed for desalinization or dialysis. Separators, as shown in the Westmoreland Patent No. 3,367,504, are quite satisfactory for the usual purposes, but because of the mesh or grid-like separator found in such devices, sediment or other turbulence-causing agents tend to foul the membrane and the mesh and thereby interfere with flow of fluid.

Detailed Description Text (10):
Accordingly, the present membrane module 10 has for its principal object the elimination of the mesh and also provides an improved control geometry of the feed flow. The present construction provides a long path with a relatively decreased cross sectional area to permit the flow of copious amounts of fluid for high velocity. This is accomplished by utilizing only a minimum amount of separating mesh, such as the entering or exiting mesh strips 48 and 49, and lateral supporting strips 50, each being approximately one inch wide. The object is to minimize, as far as possible, the use of mesh or grid-like separators, to thereby minimize impedance of feed flow through the membrane cell.

Detailed Description Text (11):
The embodiments illustrated in FIGS. 4 and 5, and an alternative disclosed in FIG. 6, disclose the meandering or serpentine path, wherein the envelope 41 containing the backing layers 45 and membrane layer 44 are shown attached to the tube or mandrel 24. The apertures 25 of the tube 24 are exposed to collect fluid flowing through the semipermeable membrane 44. Fluid flow is shown by means of the arrows in FIGS. 4 and 5. It will be observed that entrance of the fluid will be through the relatively short mesh entrance or inlet strip 48 communicating with the apertures 31 of the upper spider 30 (see also FIGS. 1 and 2), which apertures in turn communicate with the chamber 12 for collection of entering fluid from the inlet pipe 15. A plurality of channel spacer or separator members or strips 53 are disposed in parallel, spaced apart relationship with respect to one another and with marginal channel strips 54, 55, and 56 to define the feed flow channel or

paths. The strips or spacers 53-56, inclusive, are of sufficient thickness to provide the channel or fluid path for each convolution when the membrane module 10 is spirally wound upon the tube 24. The material of the spacers is not of particular importance, other than it should be impermeable with respect to the fluid to act as a barrier and guide for the fluid flow. Polyethylene or a soft polyvinyl chloride, for instance, may be acceptably used for this purpose. Thus, fluid entering the short mesh inlet strip 48 will follow the arrow path from right to left with respect to FIG. 4, and thence along the next arrow path to the end of the overwrap 42 and then outwardly of the exiting or outlet mesh strip 49 to the lower spider 30 and thence exiting at the outlet pipe 19. The permeate, itself, will enter the apertures 25 of the central tube 24 to exit through the tubular portion 26.

Detailed Description Text (14):
Tests of the improved membrane module 10 were conducted during the summer months of July and August in the mouth of the Appomattox River known for its high turbidity. The water temperature ranged between 83.degree. F. and 90.degree. F. As a result the water was high in turbidity and biologically active, with turbidities ranging from 20 to 60 NTU'S. Total turbidity peaks resulting from boat traffic ranged from 100 to 1,000 NTU's. The feed water was composed primarily of sodium chloride, sodium bicarbonate and calcium bicarbonate. The pH was less than 7 indicating a relatively high carbon dioxide concentration, further indicating high levels of bacteria which produce the carbon dioxide.

Detailed Description Text (16):
Tests indicate that the velocity of the water over the surface of the reverse osmosis membrane was an important factor. It affects the rate of fouling of the membrane with suspended solids. The lower the flow rate or velocity, the faster the reverse osmosis membranes fouled.

Detailed Description Text (17):
The test results, in this highly turbid media, indicated that devices having mesh separators which entirely cover the area between membrane elements had fouling rates that were unacceptable. The standard elements tested had a flow path width of 55 inches by 0.030 inch thick with a path length of 18 inches. The velocity factor was 0.194 feet per second per gallons per minute. At a feed rate of 5 gpm the velocity of the water in the separator was found to be 0.97 feet per second (fps). The standard or conventional test elements were initially operated at 3.7 gpm at a velocity of 0.72 feet per second and had a pressure drop of 10 psi. This is pressure drop ratio of 13 psi/fps. The variations in pressure drop are illustrated in FIG. 7, wherein three representative curves are shown. Curve A illustrates a pressure drop of a conventional reverse osmosis element similar to that disclosed in the Westmoreland U.S. Pat. No. 3,367,504. Curve B is illustrative of a pressure drop of an open channel reverse osmosis element according to the present invention and with the thickness of the entering and exiting mesh strips being substantially equal to the thickness of the separator strips 53. Curve C illustrates the pressure drop of an open channel reverse osmosis element according to the present invention, but with the thickness of the entering and exiting strips 48 and 49 being about 33% greater than the thickness of the separator strips 53.

Detailed Description Text (18):
It is to be noted for the record that Curves A, B and C are presented for general comparison only and to illustrate considerable improvement in pressure drop occurring in the Curves B and C when compared to a conventional spiral membrane construction. That is, although the data supporting each curve is accurate, the pressure drop data for Curve A was based upon prefiltered water entering the standard or conventional element.

Detailed Description Text (19):
The improved test elements had an initial flow rate of 1.92 gpm and a velocity of

2.73 feet per second and had a pressure drop of 1.5 psi at the start of the test run. This is an increase in velocity of 379 percent with a decrease in pressure drop of 667 percent. The pressure drop ratio is 0.55 psi/fps.

Detailed Description Text (20):
The flow rate was increased to 3.8 gpm. This gave a velocity of 5.4 feet per second and a pressure drop of 3.5 psi. This is an increase in velocity of 750 percent over the standard element with a decrease in pressure drop of 286 percent. The pressure drop ration is 0.65 psi/fps.

Detailed Description Text (21):
At the maximum flow rate of 6.0 gpm, the velocity was 8.6 feet per second and a pressure drop of 15.5 psi. This is an increase in velocity of 1194 percent over the standard or conventional element with an increase in pressure drop of 155 percent. The pressure drop ratio is 1.80 psi/fps. This is a substantial improvement over the conventional design which exhibited a pressure drop ratio of 13 psi/fps at 0.72 fps.

Detailed Description Text (22):
It appears obvious that the difference in velocities and pressure drops was due to the open channel of the improved reverse osmosis elements described herein. The mesh in the conventional, prior art elements creates a substantial pressure drop. It is supposed to increase the turbulence of the water at the surface of the membrane. Instead it appears to require that the flow rate and velocity be reduced to very low levels to operate at reasonable pressure drops. It also created low velocity areas behind and beneath the strands that allow suspended solids to deposit.

Detailed Description Text (23):
It will be apparent that the advantages of the open channel spiral wound reverse osmosis elements of the present design overcome the relatively high pressure drop of the mesh of the feed separator at low feed water velocities. The mesh traps suspended solids beneath and behind the strands of the mesh, severely fouling the membrane in those areas.

Detailed Description Text (24):
Velocities of the feed water from the separator of the conventional reverse osmosis element is normally on the order of 0.75 feet per second with a maximum of 1.3 feet per second. Velocities of the feed water in the separator of the present device are normally on the order of 3 to 4 feet per second with a maximum of 9 feet per second. This range is adequate to minimize fouling by suspended solids. Removing the mesh from the element and replacing it with a narrow, open, meandering flow path separator, results in an increase in the water velocity at similar pressure drops and allows operation at much higher than normal turbidities.

Detailed Description Text (26):
An alternate, but less desirable, configuration for the feed separator is disclosed in FIG. 6. Like reference numerals refer to like elements described in connection with FIGS. 1-5. This type of separator would be suitable for normal plate and frame devices, but it is not well suited for the spiral wound, open channel, design. It does provide a good comparison to illustrate the importance of orientation in the preferred design. The primary reason for its lesser suitability is that the horizontal flow path divider strips 53a will not line up with each other as the element is wound around the permeate tube mandrel. This will cause the horizontal strips 53a to push into the upper or lower convolution and pinch off the flow channel causing excessive pressure drops. The misalignment would not provide the necessary sealing pressure to keep the feed water from crossleaking past the strips thereby short circuiting the feed flow rate. The horizontal strips could be placed so that they would overlap, but this would result in a flow path of different widths, with the narrowest widths controlling the pressure drop and velocity

characteristics.

CLAIMS:

1. In a spirally wound membrane module comprising a casing defining a cylindrical chamber, a hollow, perforated mandrel disposed in coaxial relationship with and within said chamber, said mandrel having an unobstructed bore, an elongate envelope including a pair of semipermeable membrane sheets surrounding a permeate carrier sheet and spirally wound around said hollow mandrel and separator means maintaining spacial relationship between convulated layers of said elongate envelope, wherein the improvement comprises configuring the separator means to provide a dual function of maintaining said spacial relationship and of establishing a directed, open channel feed flowpath across the width and length of the convoluted membrane envelope, and wherein said flowpath is defined by said separator means to provide a non-interrupted meandering path extending from an inlet opening in one exposed marginal edge portion of said envelope and across the area defined substantially by the length and width of said envelope, to an outlet opening defined by the opposite marginal edge portion of said envelope.

2. The module according to claim 1, wherein said feed flowpath is defined by means of laterally spaced, fluid impermeable, separator strips positioned on one surface of said membrane envelope and arranged in alternative lengthwise relationship with one another to define a serpentine configuration.

3. The module according to claim 1, wherein said separator means comprises a pair of elongate, oppositely disposed, marginal strips of impermeable material extending outwardly from said mandrel for a major length portion of one surface of said convoluted envelope, the respective distal ends of said marginal strips terminating at a point greater than the longitudinal length of the membrane envelope to provide respective inlet and outlet fluid openings, and a plurality of alternately arranged, flow directing, impermeable strips laterally spaced relative to one another and to said oppositely disposed marginal strips, whereby fluid entering and leaving said inlet and outlet openings of the convoluted membrane envelope will be caused to follow a meandering and extended path between separated convolutions of said wound membrane envelope.

4. The module according to claim 3, wherein each of said marginal strips engage porous separator strips, said porous strips extending across said inlet and said outlet openings to provide separation and compression of the convolutions of said membrane envelope and passage therethrough of fluid moving through said flowpath.

9. The module according to claim 2, wherein the said laterally spaced separator strips are arranged to have a first set of alternatively arranged strips extend from the outer surface of said mandrel and a second set juxtaposed, alternatively arranged separator strips extending toward said mandrel from the proximity of the distal end of said membrane envelope.

10. The module according to claim 2, wherein said separator means includes at least one relatively narrow support strip of porous material extending transversely of the membrane envelope and engaging said impermeable separator strips to provide lateral support and maintenance of spacing of said separator strips width wise of said membrane envelope.

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